Hyperspectral Infrared Radiation

JPL mini-symposia: The Essential Role of Long-term Satellite Records for Climate Science and Monitoring

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Introduction

- Climate monitoring requires proven stability with high accuracy and/or sensor overlap
- Focus on simple retrieval approaches that are connected as closely as possible to the measured radiances and are amenable to frequent reprocessing
- We hope to show that hyperspectral IR radiance analysis provides important measurements of climate, with minimal a-priori information
- Fusion with different remote sensing data type can reveal null space error in both, allows corrections for both sensor types (GPSRO, MLS, Imagers, etc.)

No minor gas or dust/ash retrievals using IR (future topic for mini-symposia).

No discussion of existing cloud retrievals using IR (B. Kahn, Claudia Stubenrauch for example)

Thanks to Howard Motteler, Chris Hepplewhite, and Ryan Kramer (UMBC), Stephen Leroy (AER), and Xianglei Huang (U. Mich)

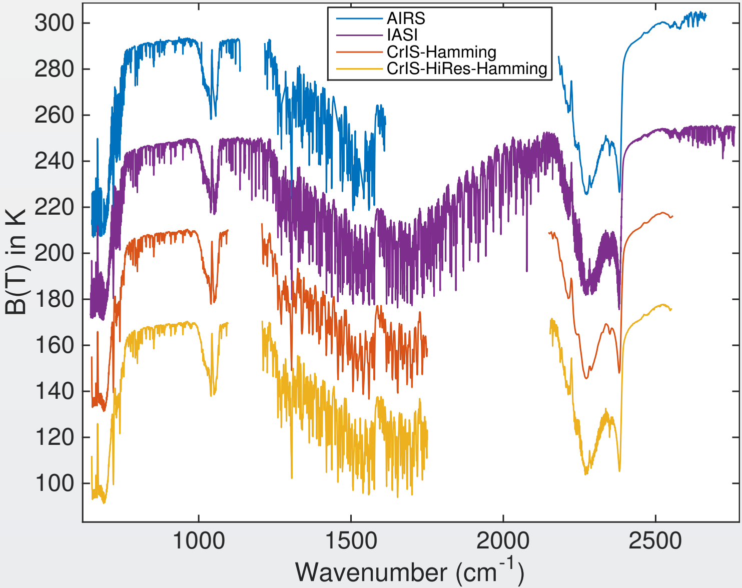
Satellite Measurements: ~12-km footprints, full coverage 2X/day

AIRS	2002 - 202X??	1:30 orbit
CrIS 1 SNPP-CrIS, 4 on JPSS	2012 - 204X?	1:30 orbit
IASI 3 on METOP-A series 3 on METOP-SG series (2024) (IASI-1 CDR available on request)	2007 - 204X?	9:30 orbit
CHIRP (AIRS+CrIS) "Virtual" L1c for climate	2002 - 204X	1:30 orbit

Each sensor produces about ~3,000,000 observations (spectra) per day.

AIRS needs reprocessing to CDR (Climate Data Record) level to fix small calibration issues.

Example Spectra

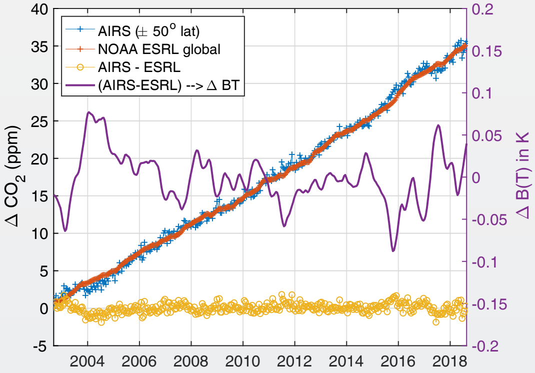


Overall Approach

- Driven by Level 2 + Time $\neq$ Climate
- Full sampling not required for climate
- Manipulate data in radiance space "as long as possible" before retrievals
- Reduce sensitivity to calibration and RTA bias (radiance anomalies)
- Optimal estimation retrievals regularized more by smoothing than a-priori
- Develop analysis approaches that encourage more researchers to use radiances, rather than complicated Level 2 products for climate research, with quick turnaround.

Working to provide CHIRP data on GES DISC AWS Cloud storage in format that allows high-speed I/O for end-user processing of radiances.

AIRS Stability Validation (Clear Ocean Scenes Time Series)



- CO_2 trend (using 400 "good" channels) suggests stability: -0.023 ± 0.009 K/decade. Picks up ENSO related variations in CO_2 growth at the 0.04K with good S/N
- CH_4 and N_2O trends exhibit small offsets (known events, fixable)
- (AIRS - GHRSST) SST trends:): -0.022 ± 0.012 K/decade
- This approach provides strong evidence of inherent radiometric stability at the climate level

Radiance Sampling

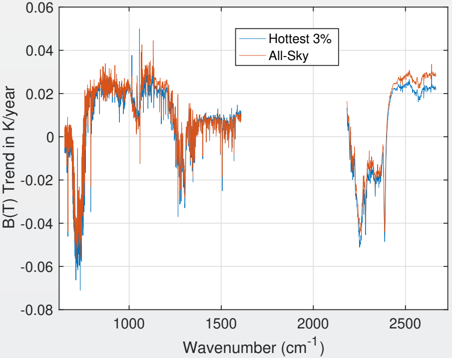
- Early testing shows identical surface T trends with 1%, 3%, 5%, and 10% hottest scenes per 16-day gridded lat/lon cell (3x5 lat/lon).
- Will this sampling provide accurate profile trends?
- Careful sampling of cloudier scenes does not preclude retrievals, just more care in cloud parameter a-priori values and parameterization
  - Hyperspectral IR retrievals really need footprint matched cloud parameters from MODIS (like CERES uses). Univ. Wisconsin has already generated this product for CrIS from VIIRS!
- Subsequent results used 3% surface T sampling (from 1231 cm^{-1} channel)

Trend retrievals in next few slides take ~1 hour max, so reprocessing is trivial.

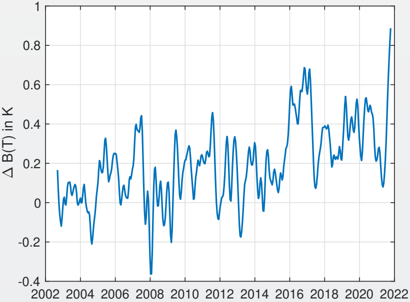
Resampling (say for fixed cloud forcing) takes ~2 days.

Global IR Radiance Trends and Surface-T Anomalies

Global Trends: Clear vs All-Sky

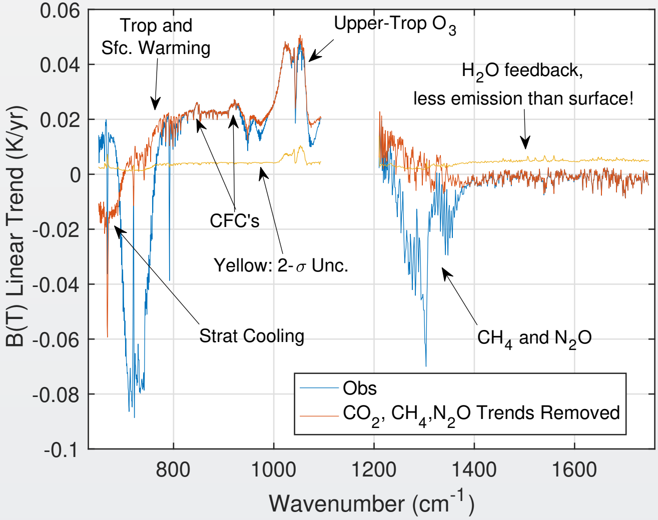


Tsurface Global Anomaly



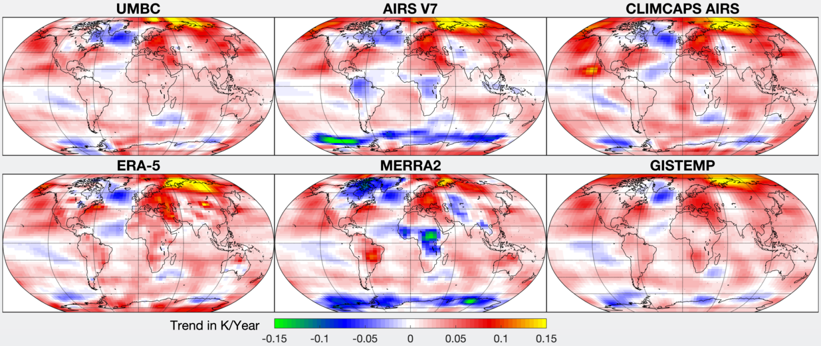
- "Clear" 3% hot sampling trends almost same as all-sky
- Zonally averaged uncertainties (inter-annual variability) ~0.05K/Decade
- Good AIRS channels: stability ~0.02K/Decade
- Some water band drifts of up to ~0.04K/Decade (can be fixed)
- Shortwave known drifts (higher for cold scenes)

Follow-On Sensor: SNPP CrIS 8-Year Trends



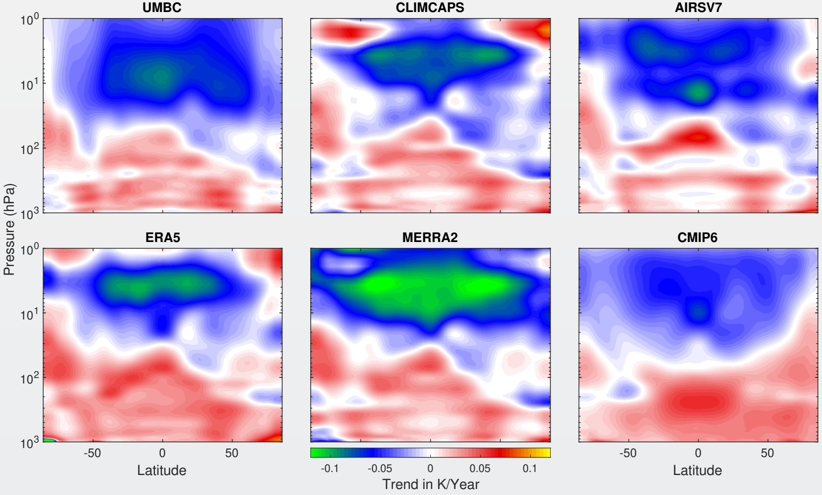
Clear ocean scenes
Less "hash" due to nature of FTS instrumentation

Surface Temperature Trend Comparisons



Data Source	Spatial Correlation (w/ UMBC)
CLIMCAPS AIRS	0.82
GISTEMP	0.74
AIRS V7	0.70
ERA-5	0.66
MERRA2	0.53

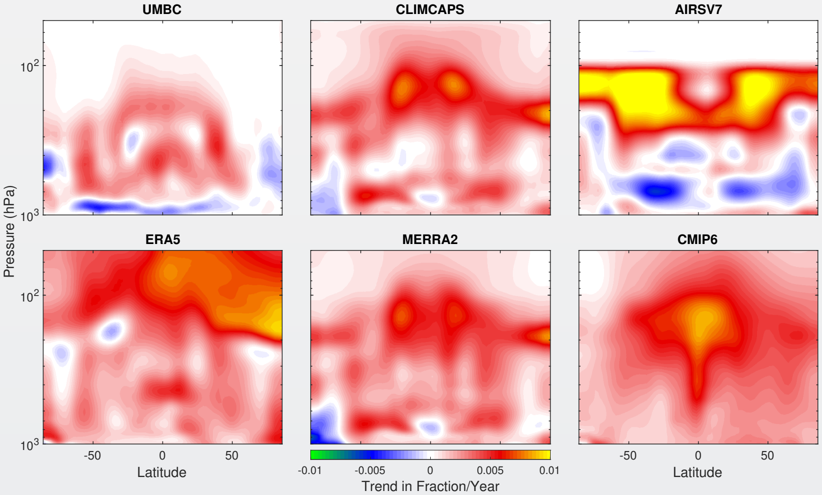
Zonal T(z) Trends (with CMIP6 to 2014)



IR does have null space near the tropopause. But trends change sign there as well, as they should.

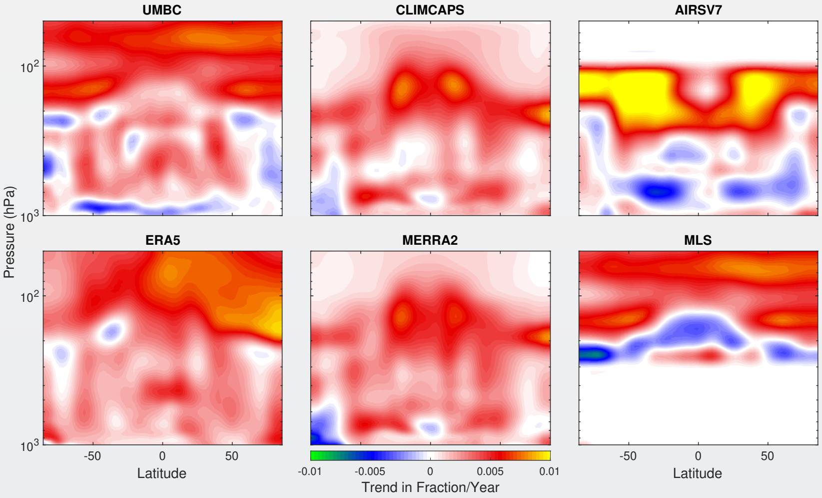
UMBC uncertainties ~0.01K/year (inter-annual variability)

Water Vapor Trends (with CMIP6 to 2014)



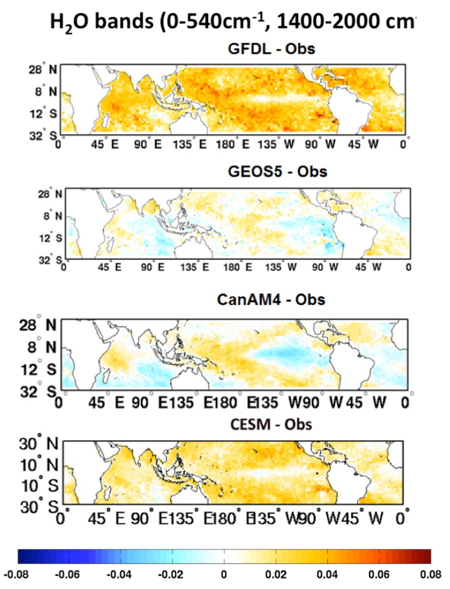
UMBC a-priori of zero influencing upper-trop WV

Water Vapor Trends (with AURA-MLS: from 2004+)



- Quick test using MLS trends as a-priori for UMBC upper-trop
- MLS water vapor unimportant for OLR applications
- Mean global Δ RH < 0.01%/year

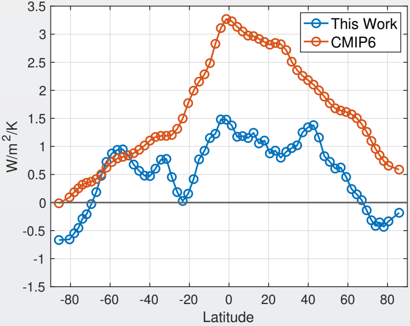
Spectral OLR Product from AIRS (Xianglei Huang U. Mich.)



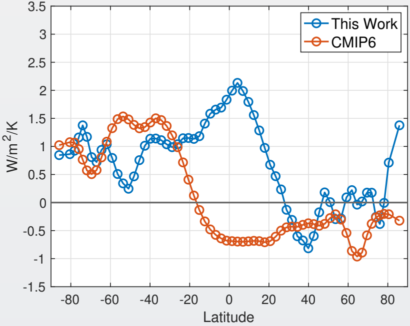
Climate Feedback Estimation from Trend Retrievals

- CMIP period ends 2014 compared to our 2002-2021 time period
- OLR differences directly from trends, no use of inter-annual variability for kernels
- UMBC results similar to ERA-5 (not shown).
- Cannot use MERRA2 surface T due to poor trends.

λ WV



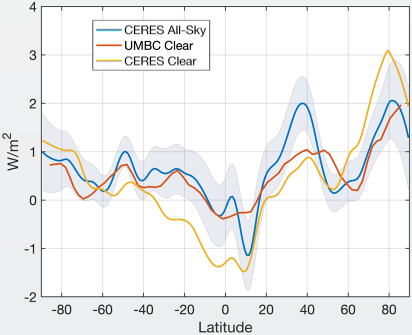
λ Lapse Rate



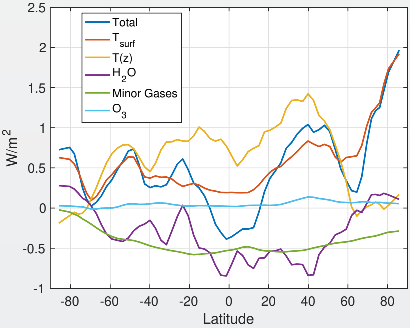
Note Positive lapse rate feedback in tropics for 2002-2022.

OLR Clear Sky Trends from AIRS (UMBC version)

Total Δ OLR (clear) over 19 Years

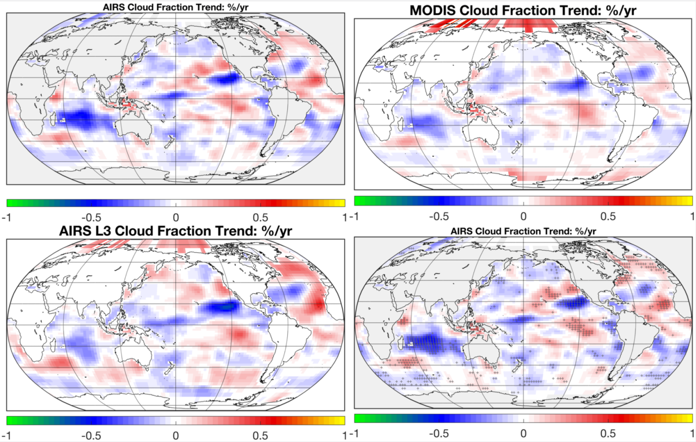


Components from AIRS Trends



- UMBC clear closest to CERES All-Sky (but not perfect)
- Hints for these differences seen in cloud forcing PDFs (in two slides)

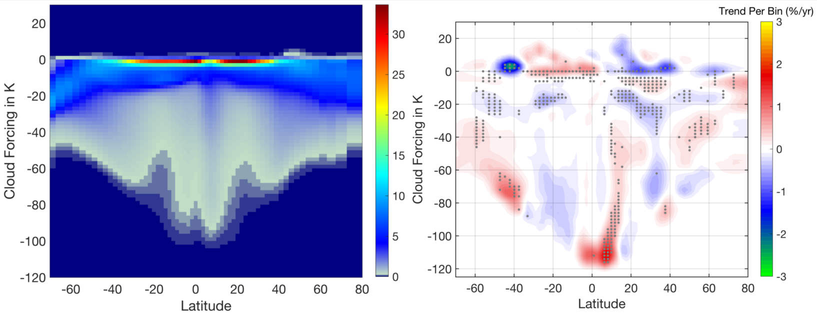
Cloud Fraction Trends (17 Years)



- Based on 16-day PDFs of 1231 cm^{-1} channel
- AIRS/MODIS global avg: -0.018/-0.010 %/year. Difference smaller than our estimated accuracy.
- Provides independent assessment of CF. Many other permutations of this approach.

Trends in PDF of Cloud Forcing (Pseudo vertical trends)

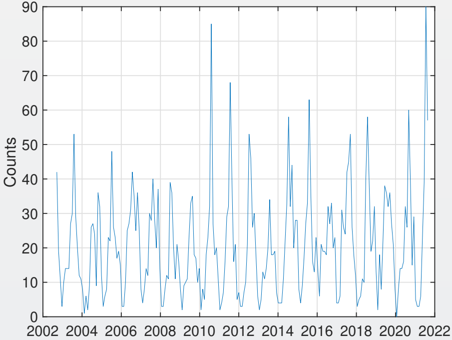
Left Panel: Zonal cloud radiative forcing (CRF) PDF yearly means, Right Panel: CRF PDF relative trends per pixel, in %/year. Regions with trends that are 2X the magnitude of the 2-σ trend uncertainties are marked with + signs.



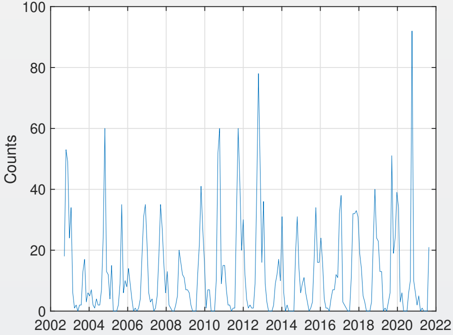
Suggests increased deep convection near the equator. VIIRS cloud products now matched to CrIS footprint at GES DISC, we need that for AIRS using MODIS.

Time Series of Large Fires (32 Day Avg)

Northern Hemisphere



Southern Hemisphere



- Retrieval of fire temperature and area looks feasible
- Technique based on statistical anomalies between LW and SW window channels in a 3x5 lat/lon grid covering 16 days.

Example of *very* quick processing of AIRS full mission data looking for hot anomalies. Easily extended to heat events, etc.

Summary and Future

- Hyperspectral IR observations are a unique dataset to monitor and understand climate change, for weather prediction and reanalysis, and to evaluate climate models
- Hyperspectral IR radiances provide insights into the physics of the climate system that are not possible using broadband observations
- We are starting to successfully merge hyperspectral IR radiances from different instruments which is critical for climate monitoring (GPSRO, MLS, MODIS/VIIRS)
- We will continue to improve these merged products using more sophisticated approaches and including additional observations
- But we need to keep these hyperspectral IR instruments alive and stable for as long as technically possible and continue to produce climate-level calibrated radiances